Steam System Improvements at Dupont Automotive Marshall Laboratory

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ABSTRACT

Dupont's Marshall Laboratory is an automotive paint research and development facility in Philadelphia, Pennsylvania. The campus is comprised of several buildings that are served by Trigen-Philadelphia Energy Corporation's district steam loop. In 1996 Dupont management announced that it was considering moving the facility out of Philadelphia primarily due to the high operating cost compared to where they were considering relocating. The city officials responded by bringing the local electric and gas utilities to the table to negotiate better rates for Dupont. Trigen also requested the opportunity to propose energy savings opportunities, and dedicated a team of engineers to review Dupont's steam system to determine if energy savings could be realized within the steam system infrastructure.

As part of a proposal to help Dupont reduce energy costs while continuing to use Trigen's steam, Trigen recommended modifications to increase energy efficiency, reduce steam system maintenance costs and implement small scale cogeneration. These recommendations included reducing the medium pressure steam distribution to low pressure, eliminating the medium pressure to low pressure reducing stations, installing a back pressure steam turbine generator, and preheating the domestic hot water with the condensate. Dupont engineers evaluated these recommended modifications and chose to implement most of them.

An analysis of Dupont's past steam consumption revealed that the steam distribution system sizing was acceptable if the steam pressure was reduced from medium to low. After a test of the system and a few modifications, Dupont reduced the steam distribution system to low pressure. Energy efficiency is improved since the heat transfer losses at the low pressure are less than at the medium pressure distribution. Additionally, steam system maintenance will be significantly reduced since 12 pressure reducing stations are eliminated.

With the steam pressure reduction now occurring at one location, the opportunity existed to install a backpressure turbine generator adjacent to the primary pressure reducing station. The analysis of Dupont's steam and electric load profiles demonstrated that cost savings could be realized with the installation of 150 kW of self-generation. There were a few obstacles, including meeting the utility's parallel operation requirements, that made this installation challenging.

Over two years have passed since the modifications were implemented, and although cost savings are difficult to quantify since process steam use has increased, the comparison of steam consumption to heating degree days shows a reducing trend. Dupont's willingness to tackle energy conservation projects without adversely affecting their process conditions can be an example to other industrial steam users.

INTRODUCTION

Dupont's Marshall Laboratory has been an automotive paint research and development facility in Philadelphia, Pennsylvania since the early 1900s. The first building was built in 1901, before it was a Dupont site. Dupont has developed several automotive paint innovations at this Philadelphia site. While their primary R&D focus is the development of better automotive paints, Dupont Marshall Lab scientists and engineers also work on other projects such as developing improved computer printer inks.

Several buildings receive steam from Dupont's aboveground and buried steam distribution piping. The Trigen steam loop supplies steam under the streets of Philadelphia to Dupont Marshal Lab and over 300 other customers, including the University of Pennsylvania, the U.S. Mint, the Philadelphia Art Museum, and most of the center city hospitals. The majority of the steam is generated from the Grays Ferry Cogeneration Plant, which is a combined cycle (brayton cycle and rankine cycle) cogeneration plant that includes a dual fuel (gas and oil) combustion turbine generator and a steam turbine generator. This plant provides 150 MW to the local electric grid operated by PJM Interconnection LLC, and can produce up to 1.4 million pounds of steam/hour.

When Dupont notified city officials in 1996 that it was considering moving their research and development facility to the south due to the high cost of operating in Philadelphia, and energy costs were a significant component of their operating costs. The city responded by bringing the local electric and gas utilities to the table to negotiate better rates for Dupont. Since Dupont was one of Trigen's largest and most valued steam customers, Trigen dedicated a team of engineers to review Dupont's steam system to determine if energy savings could be realized within the steam system infrastructure.

Steam System Recommendations

After walking down the Dupont steam system and listening to Dupont engineers describe how the steam is used in different areas, Trigen recommended modifications to reduce heat transfer energy losses, reduce steam system maintenance costs and implement small-scale cogeneration. Specific recommendations included reducing the medium pressure steam distribution to low pressure, eliminating the medium pressure to low pressure reducing stations, installing a backpressure steam turbine generator, and recovering the heat from the condensate. Dupont engineers and an independent energy consultant evaluated the recommended steam system modifications and decided to go forward with them, except for the recommendation to preheat the domestic hot water.

Steam Distribution Efficiency Gain

Dupont received steam from Trigen at 210 psig, and reduced it all to 150 psig in a pressure reducing station. Some of this steam was used at 150 psig for process use, and the rest was reduced to 120 psig in another pressure reducing station to be distributed to several buildings. The steam pressure was further reduced to 15 psig at 12 separate pressure reducing stations where the steam was used for heating, humidification and domestic hot water.

Since Dupont had received steam from the steam loop for several years, historical hourly steam consumption was readily available. Trigen metered the steam with a vortex meter and an automatic data acquisition system that downloading the data to Trigen via modem. An analysis of Dupont's past steam consumption showed that the steam distribution piping system sizing was acceptable if the steam pressure was reduced from 120 psig to 15 psig. The basis for this determination was to keep the steam velocity below 6000 feet per minute (fpm) to avoid excessive noise, premature wear, and significant pressure drop. In a process steam environment, a steam velocity as high as 12,000 fpm would be acceptable if noise is not a factor, but a significant portion of this Marshall Lab facility is office or research areas where noise would be a distraction. The steam velocity can be calculated simply by using the following equation:

$$V = 2.4QVs/A \qquad \text{Equation (1)}$$

Where:
V = Velocity in feet per minute
Q = Flow in lbs/hr steam
Vs = Sp. Vol. In cu. Ft/lb at the flowing pressure
A = Internal area of the pipe in sq. in. [1]

Given a maximum velocity of 6,000 fpm, the maximum steam flow throughout each section could then be calculated. Dupont provided piping drawings showing the diameter of each pipe section. Unfortunately the exact steam flow to each building was not known since there were no submeters. However, in all cases, the calculation of the maximum allowable steam flow in each section was greater than the rule of thumb amount of steam/sq.ft. heating area needed for each building. In order to ensure a successful transition to low pressure distribution, a test of the system was conducted using the manual bypasses around each of the low-pressure pressure reducing valves (PRV) and adjusting the pilot at the main pressure reducing valve to slowly reduce pressure from 150 psig to 15 psig. Fortunately, with only one exception, the bypasses around the PRV stations were also properly sized for low-pressure steam. After a successful test of the system and a few minor modifications, Dupont reduced the steam distribution system to low pressure.

This modification improved energy efficiency since the heat transfer losses through the pipe and insulation at a lower temperature are less than the heat transfer losses at a higher temperature. An estimate of reduced condensate losses was estimated using the following equation at 125 psig and at 15 psig:

$$C = (A * U * (t_1 - t_2) * E)/H \qquad \text{Equation (2)}$$

Where:
C = Condensate in lbs/hr-foot
A = External area of pipe in square feet
U = Btu/sq ft/degree temperature difference/hr
T_1 = Steam temperature in °F
T_2 = Air temperature in °F
E = 1 minus efficiency of insulation
H = Latent heat of steam [2]

Since all of this condensate is disposed of rather than sent to a condensate return system, minimizing condensate losses directly minimizes steam consumption.

Steam System Maintenance Savings

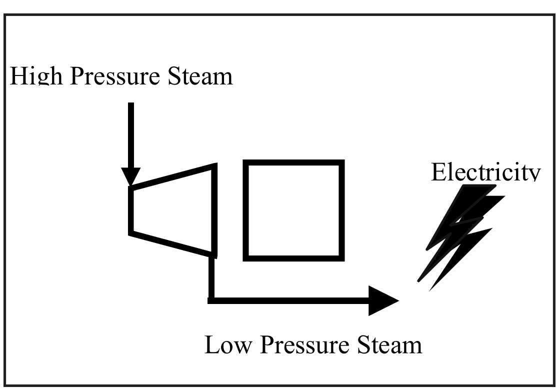
Additional cost savings are realized by the significantly reduced maintenance required since 12 pressure reducing stations are eliminated. Each pressure reducing station typically includes isolation gate valves, a bypass globe valve to enable manual throttling of the steam, a strainer, a steam trap and a pressure relief safety valve, in addition to the PRV. Properly selected PRVs need to have seats replaced about every five years, while incorrectly sized PRVs may need new seats as frequently as each year. Additionally, steam losses due to weeping safety valves and leaking flanged or screwed connections could be reduced. Although it is difficult to exactly quantify these costs, a savings of $25,000/year due to eliminating these pressure reducing stations is realistic.

Backpressure Turbine Generator Installation

Since Trigen's steam pressure supplied to Dupont is nominally 210 psig, and all of the pressure reduction could now take place at one location, the opportunity existed to consider the installation of a backpressure turbine generator. As illustrated in Figure 1, a backpressure turbine generator takes the place of a PRV by reducing the pressure from high pressure to low pressure.

While the steam is losing pressure, it is rotating a turbine that rotates a generator and generates electricity. The PRV parallel to the turbine is set about 2 psig below the turbine output to enable the PRV to automatically pick up the steam flow if the turbine trips for any reason.

In addition to needing an acceptable pressure reduction, an analysis of the electric usage is necessary to determine if installing a backpressure turbine generator is viable. Dupont was on a high-tension service electric tariff that included an electric demand ratchet payment. Basically, the billed monthly demand is the greater of the maximum registered demand during the month, or 80 percent of the peak demand during the previous June through September months. Fortunately, Dupont's annual electric load profile was flat enough such that the actual demand during the winter months was more than 80 percent of the peak demand during the summer months. Accordingly, the billed demand each month was the actual billed demand set during that month.



An analysis of Dupont's annual steam and electric loads was done to determine the optimum size for the backpressure turbine generator. Since there were no steam submeters after the main meter, the amount of steam used at low pressure was not exactly known. However, since the summer steam load was nearly all process load used at high pressure, it was safe to assume that this process load was fairly constant throughout the year. Based on the remaining load after the estimated high-pressure process load was removed, a 150 kW backpressure turbine generator was selected. Since the 150 kW output of this generator is far less than the electric capacity Dupont needed, this unit would be operating parallel to the electric service supplied by the local electric utility. The local utility required the review and approval of an application for parallel operation before the turbine generator could be installed. This is necessary to verify that the installation will operate safely in parallel to the grid, and to verify that the power quality of the grid is not reduced such that it would affect other utility customers in the vicinity. Since this generator is an induction generator, the unit is automatically synchronized by the utility electric service, and would instantly shut down if the utility service is interrupted. Ultimately, the electric utility approved the installation after a satisfactory test of the relay protection system.

The turbine generator was installed adjacent to the primary pressure reducing station. Since this pressure reducing station was located in a separate steam metering building, the electric from the turbine generator was tied into a motor control center in the adjacent building.

Preheating Domestic Hot Water

In addition to the energy conservation recommendations that Dupont implemented, preheating the domestic hot water with condensate was also recommended. Since the district steam loop in Philadelphia was installed during a time when water and energy were relatively inexpensive, the steam loop was not installed with condensate return piping. Accordingly, after the energy is removed from the steam, the remaining condensate is sent to the sewer. However, this condensate often has useful energy remaining. Also, since the local code requires the water to be 140°F before it goes to the sewer, often water must be added to it to quench the condensate as needed. Therefore, instead of wasting useful energy and potentially useful water, Trigen recommended adding a heat exchanger to transfer the useful heat from the condensate to water used for domestic hot water heating.

The amount of energy available from the condensate can easily be determined. Assuming that the condensate is saturated at 200°F, the enthalpy would be 168 Btu/lb. If the heat exchanger is designed to reduce the condensate to 100°F (based on an adequate cold water flow), the leaving enthalpy would be 68 Btu/lb. Therefore, 100 Btu/lb are available for preheating domestic hot water, which means that for every pound of steam that is used, 100 Btu can be used for preheating domestic hot water.

The amount of water used to quench the condensate to 140°F that can be avoided by preheating domestic hot water also can be easily estimated. Given the conservation of energy for a steady state energy balance, assuming the kinetic energy changes of the flow stream are negligible:

$$m_1h_1 + m_2h_2 = m_3h_3 \qquad \text{Equation (3)}$$

Where:
m_1 = mass of condensate, lbs.
h_1 = enthalpy of condensate, Btu/lb.
m_2 = mass of cooling water, lbs.
h_2 = enthalpy of cooling water, Btu/lb.
m_3 = mass of mixture, lbs.
h_3 = enthalpy of mixture, Btu/lb. [3]

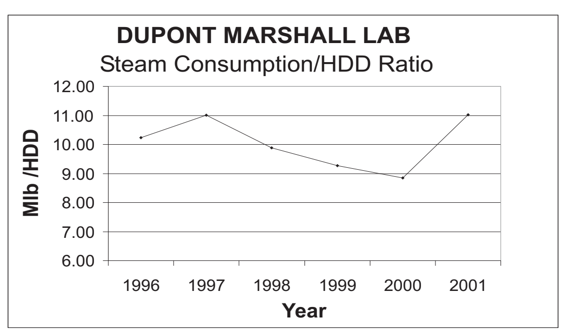
Since $m_1 + m_2 = m_3$ (conservation of mass), and all of the enthalpies are known assuming saturated condensate at 200°F, saturated cooling water at 60°F, and a saturated mixture at 100°F, the mass of the cooling water needed can be found for a given amount of condensate. It is often surprising to go through this exercise and find out the actual cost of water needed for quenching. Note that since domestic hot water is typically an intermittent need, some water would still be needed to quench the condensate when preheating is not possible.

At Dupont's Marshall Laboratory, the amount of condensate available near the domestic hot water heating is not centralized, making it difficult to assess the amount of condensate available near the domestic hot water heaters. Accordingly, we could not assess the payback on the cost of installing heat exchangers and associated piping condensate pumps and valves as needed. Therefore, domestic hot water preheating was not done to date.

Measured Savings

Over two years have passed since the modifications were implemented, and although cost savings are difficult to quantify, the comparison of steam consumption to heating degree days shows a reducing trend. Heating degree days (HDD) is basically a measure of the amount of days that heating is needed, and is calculated by subtracting the average ambient temperature from 65. Historical steam usage has shown that steam consumption is closely correlated to heating degree days. In order to accurately determine if the steam system modifications have resulted in more efficient steam use, the annual comparisons need to be relative to heating degree days. The graph shown in Figure 2 below of annual steam consumption in Mlbs (one thousand pounds) vs HDD clearly shows a trend of reduced steam consumption from the start of the modifications in 1998 through 2000.

The increase in the Mlb/HDD ratio in 2001 likely occurred due to the combination of two factors: the process steam consumption has increased, and the 2001 heating degree days were considerably lower than average, making the process load a larger percentage of the total consumption. In 2001, Dupont modified some process reactors to use high-pressure steam as the heating source. This process change added steam load at high pressure, bypassing the backpressure turbine generator and the low-pressure distribution. The heating degree days in 2001 were 3,984 compared to an average of 4,355 over the six years shown in the Figure 2 graph.



Lessons Learned

The following lessons from this case study can be applied to other industrial steam systems:

1. Ensure steam distribution pressure is as low as possible.

   Since lower pressure steam correlates to lower temperatures (assuming saturated steam), reducing the pressure as much as possible results in a lower delta T between the steam temperature and the ambient temperature, which results in less heat transfer losses. Note that this case study is based on reducing the steam pressure in a distribution system when the steam pressure at the generating source cannot be reduced. If it is possible to reduce the steam generation pressure, the efficiency gains by distributing at a lower pressure must be weighed against the reduced efficiency resulting from a steam generator operating at less than design pressure.

2. Consider backpressure steam turbine generator if steam generation pressure is greater than pressure needed at the point of use.

   Packaged backpressure turbine generators are available as small as 50 kW. If at least 3,000 lb/hr must be reduced from high pressure to low pressure, and higher cost electricity can be displaced, the opportunity exists to install a backpressure turbine generator.

3. Transparent improvements in steam systems can make a significant impact on the bottom line.

   By evaluating exactly what steam conditions are needed at the point of use, the upstream steam system design should be made as efficient as possible. If steam usage has changed since the steam system was started, there may be an opportunity to improve the efficiency.

Conclusion

The steam system improvements made at Dupont's Marshall Laboratory all involved basic concepts that were easily implemented without negatively impacting processes or building comfort. The key to this case study is Dupont's willingness to identify all energy conservation possibilities and go forward with those that provide an acceptable pay-back. All too often, the utility systems in industrial facilities are seen as a necessary evil, and energy savings projects are ignored since the capital that is saved is small compared to the overall costs at industrial facilities. However, as long as the energy savings project provides an acceptable pay back on its own merits, it should be implemented.

If all industrial steam users evaluated their steam systems and completed all modifications that provided an acceptable payback, our country would be taking a significant step toward reduced reliance on fossil fuel from other countries. Additionally, by generating a portion of the electricity without any emissions whenever the opportunity exists, we are also taking a step toward cleaner air.

References

1. Spirax Sarco, Design of Fluid Systems, 1997, p. 3
2. Armstrong International Inc., Steam Conservation Guidelines for Condensate Drainage, 1993, p. 17.
3. Wark, Kenneth Jr., Thermodynamics. 5th ed. NewYork: McGraw-Hill, 1988.